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THE STUDY OF THE ORIGIN AND PROPAGATION OF DISTURBANCES IN THE BURNING OF SOLID PROPELLANTS

Prepared for:

DIRECTOR OF ENGINEERING SCIENCES
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
ATTN: SREP
WASHINGTON 25, D.C.

CONTRACT NO. AF 49(638)-565
ARPA ORDER NO. 317-62, AMEND. NO. 3
PROJECT CODE NO. 9100

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I INTRODUCTION AND SUMMARY

This report deals with the continued investigation of the reflected-pulse method for measuring the normal acoustic admittance of burning propellant surfaces. In the current report period work has been primarily concerned with problems of instrumentation which must be resolved before meaningful tests with burning propellants can be attempted.

A first version of the circuitry for the multi-line recording system (Technical Summary Report No. 16) was completed early in the report period; however, considerable modifications were found to be necessary. The difficulties (stability and synchronization problems) have now been overcome, and the entire electronic system should shortly be operational.

It had been felt for some time that the accuracy of the pulse measurements could be further improved by increasing the number of lines per centimeter on the overlays which are used to provide a vertical scale for reading the oscillograms. (It will be recalled that the pulse records are taken on Polaroid film without a graticule; a ruled overlay, white lines on a transparent base, is then aligned with the base line of the pulse, and finally the Polaroid print and overlay are photographed together on 35-mm film.) A new master grid of 120 lines/cm (our previous overlays had 60 lines/cm) has recently been obtained from the Max Levy Company, and preliminary tests indicate that it should yield excellent replicas.

As stated in Technical Summary Reports No. 15 and No. 16, the two transducers being used are Photocon Model 752A water-cooled microphones with associated Model DG-605 Dynagage amplifiers. The microphones are rated at 0 ± 5 psig, with a dynagage output of $\mp$ 10v at the maximum rated pressure. Two major problems are encountered in connection with the use of this particular equipment:

(A) A relatively low signal-to-noise ratio results from the low sensitivity of the microphone.

(B) The large (1-inch) outside diameter of the microphone flame shield generates excessive turbulence at the point where the flat-ended microphone is mounted in the circular tube.

Problem (A) can be overcome by using somewhat larger pulses than those previously employed in the cold tests. The subject of suitable pulses and how to obtain them will be discussed in detail in the main part of this report. Problem (B) was solved by building an extension for the flame shield to provide an unbroken continuation of the interior contour of the pulse tube. This extension causes a microphone resonance around 7 or 8 kc/s, making it imperative to eliminate from the pulse as much of the higher frequencies as possible.

II A STUDY OF PULSE SOURCES

For our cold measurements, made with a rather sensitive microphone, a very satisfactory and simple pulse source consisted of a small rubber bulb fitted over the end of a coaxial cable across which a storage capacitor could be discharged. In our early burning propellant tests (see Narrative Progress Report No. 13, March 31, 1962), we replaced the cable by a length of stainless steel tubing containing two thermocouple wires embedded in magnesium oxide. The two wires are electrically tied together, and the spark occurs between the wires and the steel tubing. (We shall refer to this arrangement as a "spark rod.") At that time, we used our ordinary microphone with a protective shell; the frequency response of this device was quite good up to about 1 kc/s but fell off rapidly at the higher frequencies.

As pointed out in the Introduction, we are now using the Photocon Model 752A microphone with a modified flame shield. This microphone is quite adequate up to at least 6 kc/s as far as flatness of frequency response is concerned; the low sensitivity, however, requires considerable additional amplification. In Fig. 1 we show the intrinsic noise level as seen through various filters. Total amplification corresponds to a scale of 7×10^{-4} atm/cm, and the sweep rate is 500 µsec/cm. As in all other oscillogram traces displayed in this report, trace (a) is obtained with a variable rejection filter set to exclude frequencies from 6 kc/s to 200 kc/s; the appreciable width of the trace results from the rf-output of the Dynagage amplifier which employs a circuit tuned to about 750 kc/s. Traces (b), (c), and (d) are obtained with a variable band-pass filter set at 1-6, 1-4, and 1-3 kc/s respectively. It is evident that all traces, except perhaps (d), are too noisy to permit us to measure a pulse whose filtered component has a peak-to-peak amplitude of, say, 2×10^{-3} atm (3 cm), against a noise level not exceeding about 0.5% of the signal. On the other hand, it is desirable to keep the peak overpressure of the actual (unfiltered) pulse as small as possible, in order to avoid large nonlinear effects during the propagation of the pulse. One can thus establish a

certain figure of merit for the pulses, namely the ratio of peak-to-peak amplitude of the filtered pulse to the peak overpressure of the unfiltered pulse: increasing the former increases the information content of the measurement; reducing the latter reduces nonlinear effects extraneous to the physical process we wish to observe. This figure of merit refers, of course, to a particular mode of filtering. Incidentally, in assessing the behavior of a filtered trace, one must take account of the attenuation curve of the filter used. According to the manufacturer's specifications, the attenuation above the high cut-off frequency or below the low cut-off frequency is about 24 db per octave. Thus, with the high cut-off set at 3 kc/s, the 4-kc/s component of the signal will be attenuated by about a factor of 3, and the 6-kc/s component by a factor of 11.

In Fig. 2, we show the incident pulses obtained from a spark rod aligned coaxially with the pulse tube. L designates the distance between the end of the spark rod and the open end of the pulse tube, and is measured as positive if the spark rod is entirely outside the pulse tube. The microphone was mounted 6 feet from the open end of the pulse tube, and the 12-foot-long pulse tube was rigidly terminated at its other end. (This is relevant to later figures showing both incident and reflected pulses.) The spark was produced by the discharge of a 2 μf capacitor charged to 4.5 kv. Notice the shift of the base line in the (a) traces, an electrical effect involving capacitive coupling between the spark rod and the pulse tube. The increase in the amplitude of the 7-8 kc/s vibrations following the main portion of the pulse as L is changed from +1.0 to -0.5 in. probably involves the excitation of transverse tube modes and of the microphone resonance.

In Fig. 3 we show a device designed to reduce the higher frequency components of the pulse by slowing down the rate of expansion of the air heated by the spark. The pulses produced by this "check valve" pulse source are shown in Fig. 4, again for various values of L (measured from the end of the device to the open end of the pulse tube). The discharge capacitor has been increased to 8 μf in order to produce about the same peak pressure as that of the pulses in Fig. 1. Notice the considerable

increase in the figure of merit defined above. Observe again the increase in the amplitude of the high-frequency vibrations as L is decreased.

The qualitative behavior of the check-valve source is strongly affected by the intensity of the spark discharge. In Fig. 5 we show the pulse produced by this source in a configuration identical with one already studied, L = 0.5 in., but with the discharge capacitor reduced to 2 μf. (The amplification has been increased by a factor of 2.5 for this figure.) The pulse is now basically a slowly decaying sine wave of about 2 kc/s, rather similar to the kind of pulse obtained with a rubber bulb. The figure of merit is much larger than in the comparable case shown in Fig. 4.

In Figs. 6 and 7 we display pulse pairs (incident and reflected pulses), recorded at a slower sweep rate (2 ms/cm). Figure 6 shows pulse pairs obtained with the spark rod, Fig. 7 those obtained with the check valve. In both figures we include records obtained at several additional settings of the band-pass filter to illustrate the comparative behavior of different frequency components. Because of the much greater distance between microphone and termination than that used in our previous cold tests (6 ft vs. 2 ft), there is a much more pronounced difference between the incident and the reflected pulses. Notice particularly that the gain in low-frequency component due to finite-amplitude (nonlinear) effects is almost enough to balance the attenuation due to pipe friction and other dissipative processes [trace (e), Fig. 6; traces (e), (f), (g), Fig. 7, case L = 0.75 in.].

The search for a "best" pulse source is not completed. The present discussion is principally meant to be indicative of the problems involved in such a search, and of some of the general principles whose recognition serves as a guide for further work.

FIG. 1 INTRINSIC NOISE LEVEL
(a) 0-6, 200-∞ kc/sec; (b) 1-6 kc/sec;
(c) 1-4 kc/sec; (d) 1-3 kc/sec.
(Scales: 7×10^{-4} atm/cm vs. 500 μsec/cm)

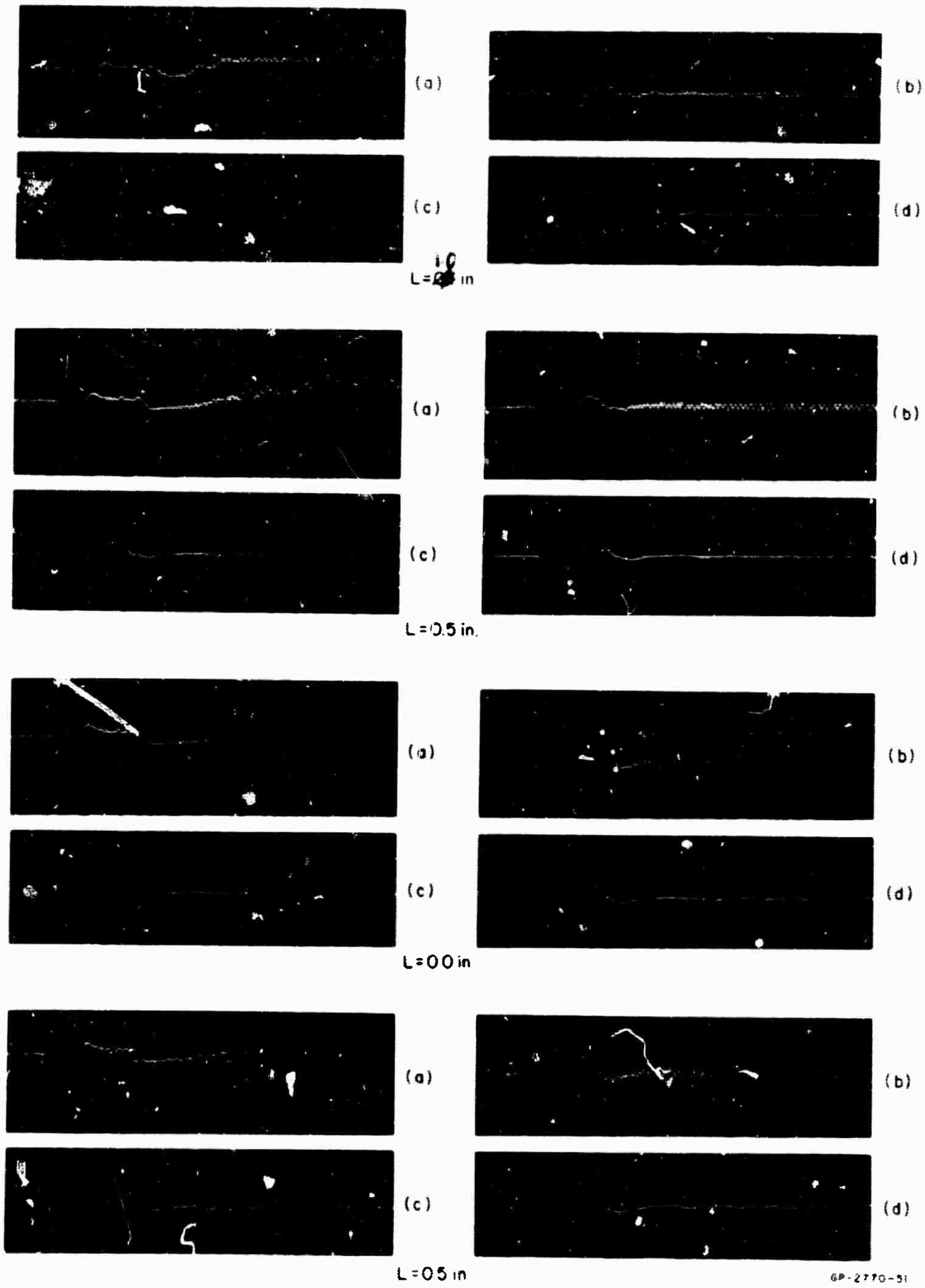

FIG. 2 INCIDENT PULSES (Spark Rod), 4.5 kv, 2 μf.
(a) 0-6, 200-1 kc/sec; (b) 1-6 kc/sec; (c) 1-4 kc/sec; (d) 1-3 kc/sec.
(Scales: 1.8×10^{-3} atm/cm vs. 500 μsec/cm)

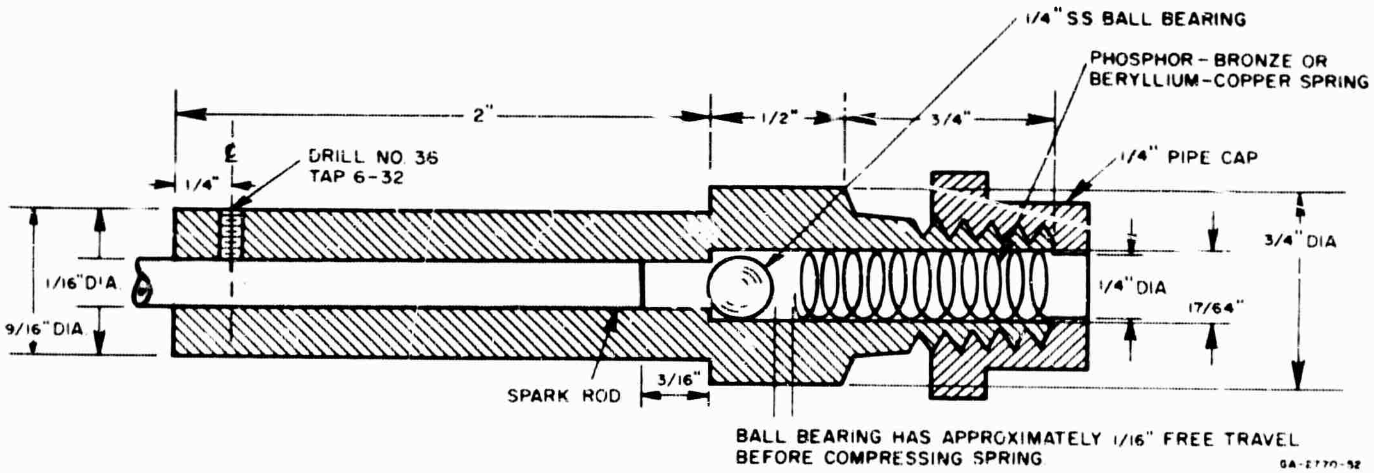

FIG. 3 CHECK VALVE PULSE SOURCE

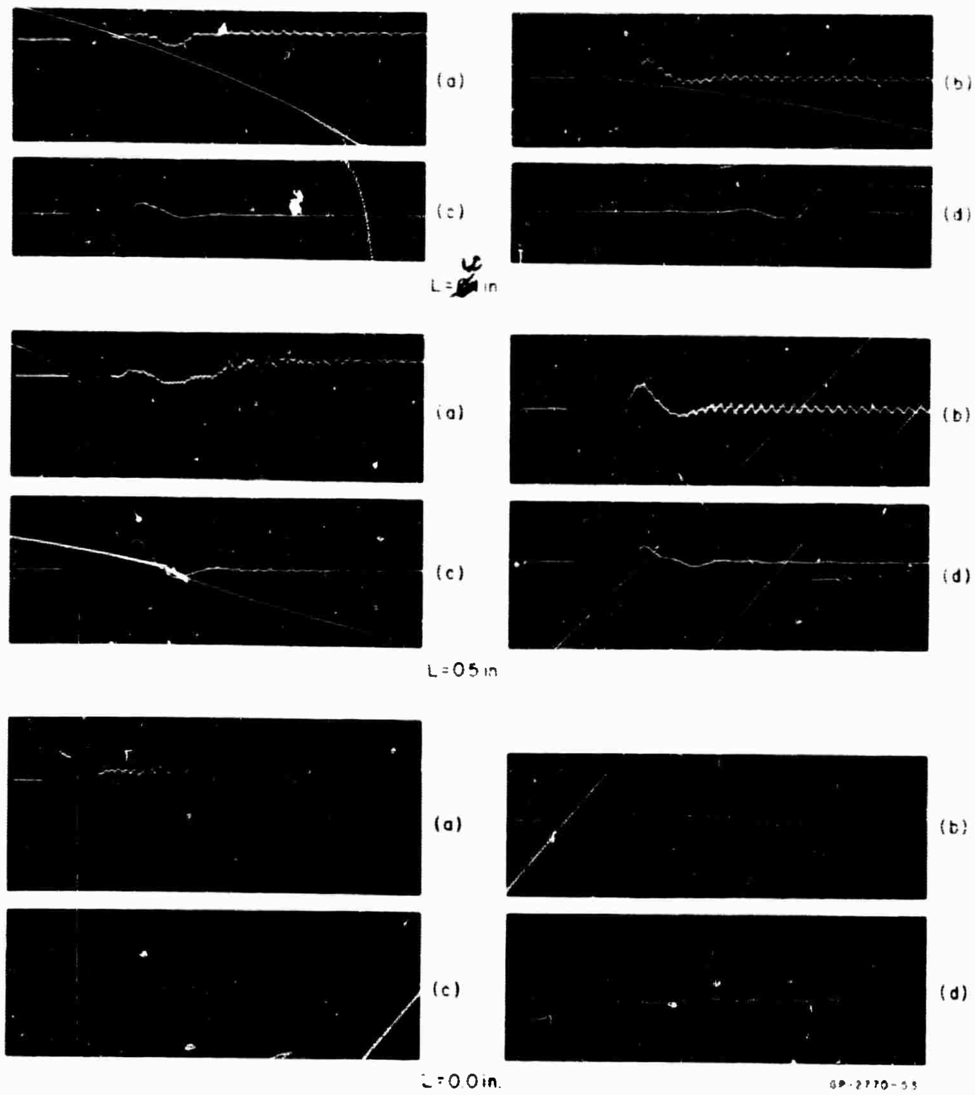

FIG. 4 INCIDENT PULSES (Check Valve Pulse Generator), 4.5 kv, 8 μf.
(a) 0-6, 200-∞ kc/sec; (b) 1-6 kc/sec; (c) 1-4 kc/sec;
(d) 1-3 kc/sec.
(Scales: 1.8×10^{-3} atm/cm vs. 500 μsec/cm)

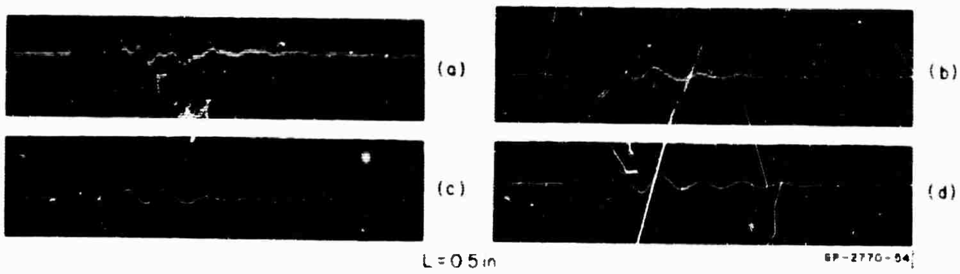

FIG. 5 INCIDENT PULSES (Check Valve Pulse Generator), 4 [illegible] kv, 2 μf. L = 0.5 IN.
(a) 0-6, 200-[illegible] kc/sec; (b) 1-6 kc/sec; (c) 1-4 kc/sec;
(d) 1-3 kc/sec.
(Scales: 7×10^{-4} atm/cm vs. 500 μsec/cm)

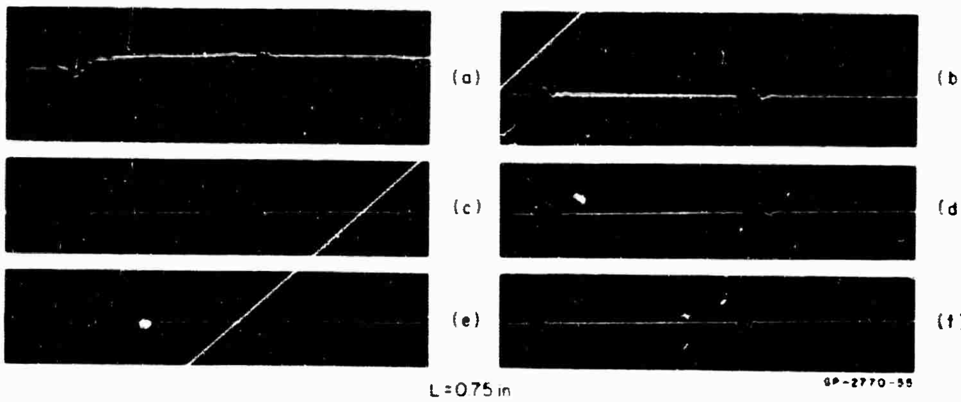

FIG. 6 PULSE PAIRS (Spark Rod), 4.5 kv, 2 μf. L = 0.75 IN.
(a) 0-6, 200-[illegible] kc/sec; (b) 1-6 kc/sec; (c) 1-4 kc/sec
(d) 1-3 kc/sec; (e) 0.4-2 kc/sec; (h) 2.5-3 kc/sec.
(Scales: 1.8×10^{-3} atm/cm vs. 2 msec/cm)

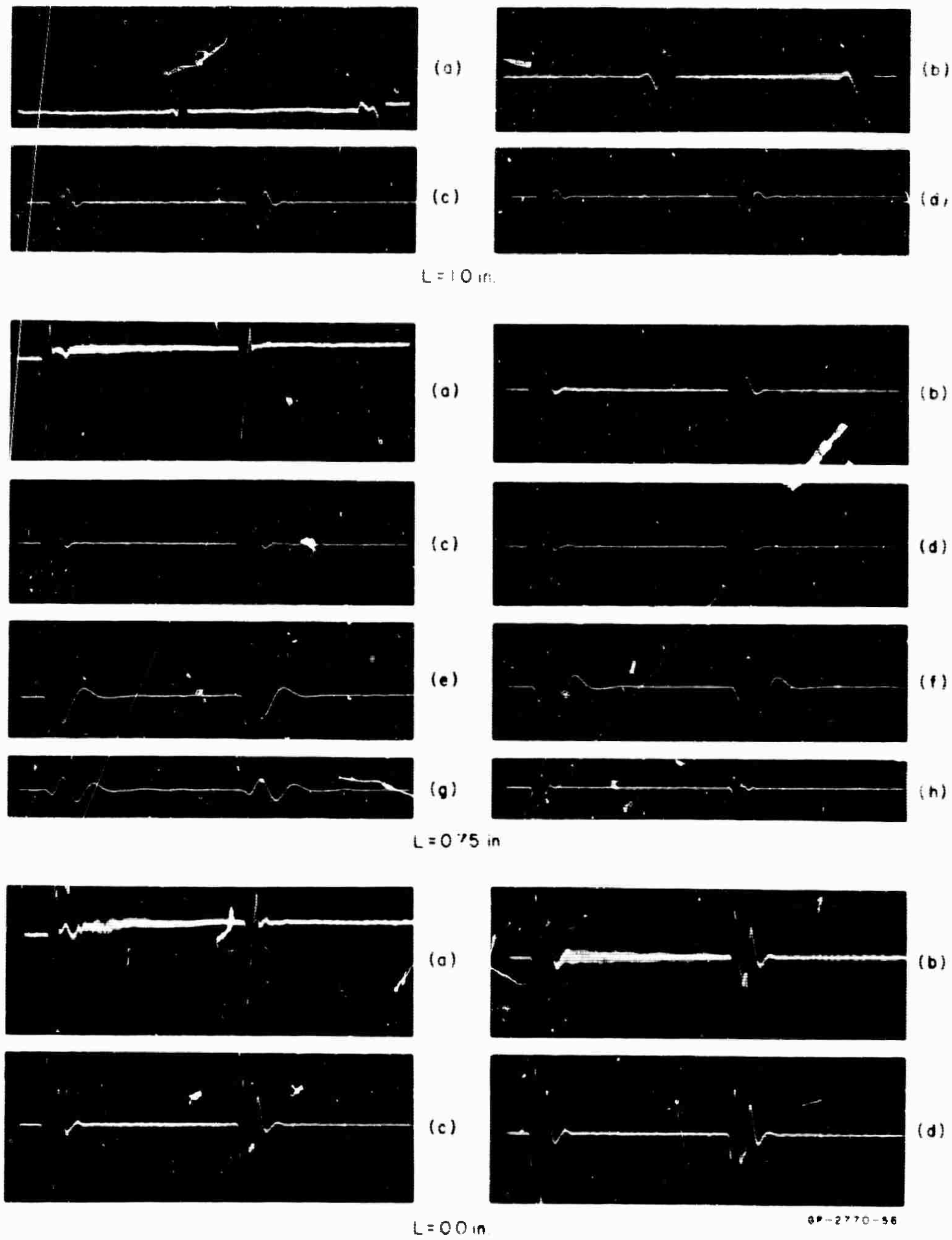

FIG. 7 PULSE PAIRS (Check Valve Pulse Generator), 4.5 kv, 8 μf.
(a) 0-6, 200-[illegible] kc/sec; (b) 1-6 kc/sec; (c) 1-4 kc/sec
(d) 1-3 kc/sec; (e) 0.4-2 kc/sec; (f) 0.4-1 kc/sec
(g) 0.4-0.7 kc/sec; (h) 2.5-3 kc/sec.
(Scales: 1.8×10^{-3} atm/cm vs. 2 msec/cm)

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